Space Weather Effects on the Performance of Satellite-based Communication Systems

Space weather and radio communication

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Abstract—**Effects of space weather on the performance of satellite-based communication/ navigation systems have been studied for several decades. A major concern is the predictability of these effects. Apart from the effects produced by changes in the large-scale distribution of plasma in the ionosphere, it is the sub-kilometer structures that appear in the ionosphere that are of great concern as they give rise to scintillations on trans-ionospheric radio signals. The current status of various aspects of scintillations produced by equatorial ionospheric irregularities in the context of space weather is reviewed here.**

Keywords - space weather; equatorial ionosphere; irregularities; scintillations

I. Introduction

In the equatorial and low-latitude ionosphere, the strongest irregularities of intermediate scale sizes (~ 100m to few km), which cause significant amplitude and phase scintillations on trans-ionospheric VHF and L-Band radio signals, arise due to the growth of the Rayleigh-Taylor (R-T) instability on the bottom-side of the post-sunset equatorial F region. Non-linear evolution of this instability is expected to cause a depleted region of plasma referred to as the equatorial plasma bubble (EPB) to rise to the top-side of the equatorial F region and the development of geomagnetic field-aligned spatial structures with zonal scale sizes extending from ~ 10 cm to 100 km. The phenomenon as a whole is referred to as equatorial spread F (ESF). During daytime, the high Pedersen conductivity of the conjugate E regions connected to the equatorial F region through highly conducting geomagnetic field lines, prevents the occurrence of ESF by short-circuiting the perturbation electric field associated with the R-T instability. In addition to in-situ measurements using rocket- and satellite-borne instruments, ground-based optical and radio observations have been used to study these irregularities. Although the basic conditions for the growth of the R-T instability are present every day, ESF occurrence shows day-to-day variability. A study of the seasonal pattern of scintillation occurrence at different longitudes first suggested that to lowest order, the occurrence of scintillation-producing irregularities required that the sunset terminator be aligned with the magnetic meridian at that location [1]. This was corroborated by satellite observations [2]. The departures from this pattern in the context of space weather are discussed here.

II. Space Weather Effects

From extensive studies to identify the causes underlying the day-to-day variability in the occurrence pattern of ESF irregularities, the height of the night time equatorial F layer has emerged as one of the most important factors in the generation of these irregularities [3]. Magnetic activity can alter the zonal electric field in the equatorial ionosphere through (a) the operation of a disturbance dynamo [4] or (b) prompt penetration of the interplanetary electric field to the low latitude ionosphere during periods of undershielding/ overshielding [5] or (c) both processes acting in combination [6]. Hence the vertical drift of the nighttime equatorial F region may be significantly altered as a result of magnetic storms/substorms resulting in changes in the height of the equatorial F layer from the average quiet time pattern, which could either suppress the generation of ESF irregularities or create conditions conducive to the development of these irregularities at a local time when the R-T instability is generally not expected to grow during magnetically quiet periods. A key issue in investigations of the latter cases on the basis of ground-based observations using radar, ionosonde, or the scintillation technique, is to establish whether the observed irregularities were generated locally because ambient ionospheric conditions in the region under observation were suitable for their growth at the time of observation. This is necessary because after generation, the irregularities tend to drift eastward with the ambient plasma once the perturbation electric field associated with the R-T instability itself disappears, so the region of generation of the irregularities could be several hundreds of kilometers to the west of the point of observation.

Spaced receiver observations of scintillations on a VHF signal transmitted from a geostationary satellite and recorded at an equatorial station were used to show that the maximum cross-correlation between the two signals is low, often less than 0.5, during the nascent stage of EPBs with scintillation-producing irregularities, indicating the presence of perturbation electric fields associated with the growth of the R-T instability. The two signals become well correlated with a time lag determined by the movement of the background plasma, once the perturbation electric fields disappear indicating that the EPB had been generated at least a couple of hours earlier [7].

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This concept forms the basis for a method of identification of nascent EPBs during magnetically disturbed periods, which indicates approximately the time when the nighttime equatorial ionospheric electric field may have turned from westward to eastward as a result of magnetospheric forcing [8]. This method has been used to obtain the seasonal variation in the local time pattern of magnetic activity linked generation of EPBs with intermediate scale irregularities in the night time equatorial ionosphere [9].

In addition to the identification of ambient conditions that favour the generation of intermediate scale irregularities in the equatorial and low-latitude ionosphere, there are other important issues as far as effects of ionospheric scintillations on the performance of satellite-based communication/ navigation systems is concerned. One of these is the evolution of the irregularity spectrum in the intermediate scale range during the non-linear growth of the R-T instability, which depends on the ambient conditions [10]. This has a bearing on the occurrence of scintillations on L-band and higher frequency radio signals, which requires the presence of irregularities of scale sizes of a few hundred meters or less [11]. Another issue is the latitudinal extent of scintillations, which depends on both the height of the background equatorial F layer and the perturbation electric field associated with the R-T instability which carries the irregularities to greater heights above the dip equator so that they map down to higher latitudes. Spaced receiver scintillation data from an equatorial station have been used together with some ionosonde and VHF backscatter radar data, and theoretical modeling of scintillations, to address some of these areas of concern as far as effects of space weather on the performance of satellite-based communication/ navigation systems are concerned.

III. CONCLUSIONS

Past studies of the day-to-day variability in the occurrence of ESF irregularities have focused on the ambient conditions required for the growth of these irregularities. This is a complex phenomenon involving the interplay of several varaiables such as the height of the nighttime F layer, Pedersen conductivity of the conjugate E regions, and thermospheric winds. Hence prediction of the occurrence of ESF continues to be a challenge. However, apart from the occurrence of these irregularities, there is day-to-day variation in the evolution of the irregularity spectrum as well as perturbation electric field fluctuations associated with the R-T instability. Transient events on the Sun such as coronal mass ejections, and high speed solar wind streams, which come from solar coronal holes and are the dominant cause of geomagnetic activity during the declining phase of the solar cycle, may cause changes in the ambient conditions in the post-sunset equatorial ionosphere through a complex solar wind-magnetosphere-ionosphere coupling. This affects the generation of the intermediate scale ESF irregularities, as well as their spectrum, and therefore both these aspects are important components of space weather.

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